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Log Treatments for Bark Beetle Control *in connection with the* Dutch Elm Disease

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FOREWORD

BY DONALD L. COLLINS

Assembled in this bulletin are the principal data from a series of log treatment experiments carried out at the Dutch elm disease research laboratory of the New York State College of Agriculture. Because of the war, a number of experiments that were in progress were not completed, and others that had been planned were not begun. It was decided, therefore, to present all of the results of the work at this time, so that pertinent information can be considered in the light of the specific requirements of local Dutch elm disease control programs.

Log Treatments for Bark Beetle Control

in connection with the

Dutch Elm Disease

DONALD P. CONNOLA, DONALD L. COLLINS,
AND LYLE E. HAGMANN

DEAD elm wood suitable for bark beetle breeding is probably the most important single factor in the maintenance and spread of the Dutch elm disease pathogen.¹ The two species which are most important as carriers of the fungus in this country are *Scolytus multistriatus* Marsham and *Hylurgopinus rufipes* Eich. The disease organism is harbored in bark beetle brood galleries made in wood from healthy trees as well as in wood from diseased trees (Collins, Donald L., and associates, 1940; Rankin, W. H. and associates, 1941), and is carried out and distributed by the beetles which emerge. The proper disposal of dead and dying elm wood which is suitable for bark beetle breeding, even if it is not from diseased trees, is therefore an essential feature of local Dutch elm disease control programs.

The most reliable method of disposing of elm beetle wood is to remove and burn the condemned material. However, there are conditions under which this cannot be done without using more time and labor than are available. There are also situations in which some method by which the wood could be saved would be preferable. This is particularly true when sanitation is left up to an individual tree owner, with reference to wood which has already been cut for fuel purposes, and where the removal and burning of uncut material would cost more than an owner is willing to spend. Tests made by this laboratory² from 1939 through 1942 under a variety of conditions have indicated that although burning is the most reliable method of rendering elm wood

¹ The fungus *Ceratostomella ulmi* (Schwartz) Buismann.

² The Dutch elm disease laboratory of the New York State College of Agriculture, located at the Boyce Thompson Institute, Yonkers, New York.

completely safe, there are a number of treatments that can be applied to condemned wood with a fair chance of success, if the attendant conditions are carefully watched. Several of these methods would require less time and labor in specific instances than removal and burning, and they would certainly be better than no treatment, even if not entirely successful. It is the purpose of this bulletin to describe briefly the experiments in this field that have been done at this laboratory. These are divided into two principal categories: (1) Tests of chemicals as repellents, and for killing beetles already present; and (2) Studies of mechanical measures and ecological factors which might be utilized to prevent beetle breeding or to reduce it to negligible proportions.

Many of the experiments described in this bulletin were made possible by the assistance of Dr. W. H. Rankin, in charge of the Dutch Elm Disease Control division of the New York State Department of Agriculture and Markets. Men from Dr. Rankin's office assisted in locating, cutting, collecting, and assembling much of the wood used in the field tests, and in obtaining permission to locate tests on certain properties. The generous assistance of the Boyce Thompson Institute, especially through Mr. Harry Beale, Superintendent of the Boyce Thompson Institute Arboretum, was indispensable in many experiments. Members of the Cornell laboratory staff whose cooperation or assistance should be acknowledged were Dr. K. G. Parker and Dr. L. J. Tyler of the Department of Plant Pathology.

I. TESTS OF CHEMICALS

The choice of chemicals to be used in these tests was influenced to a considerable extent by results obtained by workers in related fields. Craighead (1922) tested several formulae for preventing "insect attack to crude forest products such as green saw logs and timbers used in rustic construction". Several of these mixtures, or modifications of them, notably light mineral oils carrying creosote and a fumigant, have become the basic ingredients of most of the successful sprays developed for these purposes.

The work of the Berkeley, California, Laboratory of the U. S. Bureau of Entomology and Plant Quarantine, Division of Forest Insects Investigations, in the chemical control of bark beetles of western forests has been summarized by K. A. Salman (1938). The material mentioned by him as giving best results was a light distillate type of oil in which crude flake naphthalene was dissolved.

Morley (1939), with the pine sawyer (*Monochamus* sp.) as the test insect, tried arsenicals, fluorides, fluosilicates, various coal tar derivatives, lime sulfur, and other materials, alone and in combination, both

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as dusts and sprays. A mixture containing lime sulfur and sodium arsenite was considered to have given promising results as a repellent. Morley also tried some of the formulae suggested by Salman for killing larvae, with similar results.

For controlling bark beetles and other borers attacking fruit and shade trees, a number of formulae containing naphthalene, paradichlorobenzene and similar fumigants, mixed in oils and oil emulsions, or used in the pure form, have been developed (Chandler, 1939; Farrar, 1939; Hess, 1940). Johnson and Fenton (1939) tested paraffin, paradichlorobenzene, carbolineum, naphthalene, and creosote against *Chrysobothris femorata* Oliv. (the flat-headed apple-tree borer) and found the most promising formula to be one containing carbolineum, paraffin, naphthalene, flour, and soap. A kerosene and soap emulsion with paradichlorobenzene was found to kill the locust borer, *Cyllene robiniae* Forst. (St. George and Beal, 1932).

Of the large number of chemicals tested by M. B. Christian and T. E. Snyder (Christian, M. B., 1939, 1940; Snyder, T. E., 1941) for the control of powderpost beetles (*Lyctus* sp.) and ambrosia beetles (Platypodidae and Scolytidae) three of the more promising were selected for our tests, namely para-chloro-phenoxy-ethoxy-ethyl-chloride, para-tertiary-butyl-phenoxy-ethanol, and dichlorodiphenyloxide.

In addition to the information furnished by investigators in the papers cited, suggestions and information were received in conversations and correspondence with W. B. Becker, R. G. Brown, J. C. Evenden, R. B. Friend, S. E. Flanders, Robert Furniss, F. P. Keen, J. M. Miller, K. A. Salman, T. E. Snyder, P. P. Wallace, and J. S. Yuill.

The principal reports on tests for the specific purpose of controlling the breeding of *Scolytus multistriatus* and *Hylurgopinus rufipes* with chemical log sprays have been by J. J. Franzen, Philip Wallace and R. R. Whitten. Franzen (1939) tested many materials against *Scolytus* and he concluded that "it is not possible to render the trees unsuitable for beetles to cut their egg tunnels, by spraying or treating them with chemicals". He found some that were definitely repellent, however, particularly coal tar or water-gas tar, and carbolineum. He thought that only carbolineum was really practical for spraying woodpiles, but added that it was an expensive and "not completely satisfactory" treatment. Wallace (1940) found that logs completely covered with liquid coal tar creosote were entirely free from beetle attack, but that untreated logs placed among them were not satisfactorily protected. Water dilutions of miscible oils were not good repellents. Whitten (1942) studied the effects of various light petroleum oils as carriers of such fumigants as orthodichlorobenzene, and also used water emulsions. He tested for both repellency and toxicity, selecting 19 formulae for consideration in the paper. Since no demonstrable differences in effect appeared

among the petroleum oils, only the cheapest ("fuel oil") was used in the work reported. Certain spray formulae which appeared to be toxic or repellent in laboratory experiments were tried in the field, and a mixture of fuel oil and orthodichlorobenzene and one of fuel oil and monochloronaphthalene were found to be effective repellents. The former was effective also in toxicity experiments. Whitten (1945) has more recently found that sprays containing DDT may have considerable promise, both in preventing infestation and in killing beetles emerging from sprayed logs.

Materials and methods. The mixtures used in the chemical treatments described in this bulletin were made up from the materials named in the following list.

List of materials included in spray mixtures,
and companies which supplied them.

1. Kerosene	Socony Vacuum Oil Co. Inc.
2. Fuel oil No. 2	Socony Vacuum Oil Co. Inc.
3. Diesel oil	Socony Vacuum Oil Co. Inc.
4. Crankcase oil (garage wastes)	_____
5. Technical turpentine	Hercules Powder Co.
6. Sulphate wood turpentine	Sherwin-Williams Co.
7. Pulp mill liquid ("crude sulphate wood turpentine")	Sherwin-Williams Co.
8. Shell Aromatic Oil No. 2 (also known as No. 8171)	Shell Oil Co.
9. Creosote	Barrett Co.
10. Cresylic acid	_____
11. Pyridine	_____
12. Creosote oil	_____
13. Carbolineum	_____
14. Naphthalene	Barrett Co.
15. Orthodichlorobenzene	Hooker Electrochemical Co.
16. Paradichlorobenzene	Solvay Process Co.
17. Trichlorobenzene	Hooker Electrochemical Co.
18. Chlorinated toluene	E. I. duPont deNemours & Co.
19. Dinitro-ortho-cyclohexylphenol	Dow Chemical Co.
20. Dichloroethylether	Union Carbide & Carbon Corp.
21. Ethylene dichloride	Union Carbide & Carbon Corp.
22. Parascalcide	B. G. Pratt
23. Elgetol	Standard Agricultural Chemicals Inc.
24. Cedar oil	_____
25. Tergitol Penetrant No. 7	Union Carbide & Carbon Corp.
26. Paraffin oil	_____
27. Melted paraffin	_____
28. Para-chlor-phenoxy-ethoxy-ethyl-chloride	Dow Chemical Co.

29. Para-tertiary-butyl-phenoxy-ethanol Dow Chemical Co.
 30. Dichlorodiphenyloxide Dow Chemical Co.

These chemicals were combined in various ways or used alone, to make up the formulae which were used in the experiments. The designation *LT* prefixed to formula numbers stands for "log treatment". Thus *LT-1* refers to "log treatment formula number 1". The designation *H* prefixed to formula numbers merely distinguishes another series of formulae tested. The formulae used are included in the following list.

List of formulae used in tests

(The proportions given are in terms of the units of measurement actually used.)

LT-1	Kerosene	4 quarts
	Creosote	1 quart
LT-1A	Kerosene	3 quarts
	Creosote	1 quart
LT-2	Kerosene	4 quarts
	Creosote	1 quart
	Paradichlorobenzene	1 pound
	Melted paraffin	1 pound
LT-2A	LT-2	64 ounces
	Pyridine	8 ounces
LT-3	Kerosene	22 ounces
	Pyridine	2 ounces
LT-4	Kerosene	22 ounces
	Pyridine	2 ounces
	Melted paraffin	4 ounces
LT-5	Cedar oil	
LT-7	Creosote	
LT-8	Crankcase oil	3 quarts
	Creosote	1 quart
LT-9	Turpentine (tech.)	3 quarts
	Creosote	1 quart
	Paradichlorobenzene	1 pound
LT-10	Sulphate wood turpentine	3 quarts
	Carbolineum	1 quart
	Paradichlorobenzene	1 pound
LT-13	Crankcase oil	3 quarts
	Creosote	1 quart
	Paradichlorobenzene	1 pound
	Melted paraffin	1 pound

LT-18	Crankcase oil	3 quarts
	Kerosene	1 quart
	Creosote	1 quart
	Naphthalene flakes	1 pound
	Melted paraffin	1 pound
LT-19	Fuel oil	1 quart
	Turpentine (tech)	1 quart
	Creosote	1 quart
	Paradichlorobenzene	1 pound
	Paraffin oil	1 quart
LT-24	Crankcase oil	3 quarts
	Creosote	1 quart
	Orthodichlorobenzene	1 pint
	Melted paraffin	1 pound
LT-29	Fuel oil	3 quarts
	Creosote	1 quart
	Naphthalene flakes	$\frac{1}{2}$ pound
	Melted paraffin	$\frac{1}{2}$ pound
LT-30	Diesel oil	3 quarts
	Creosote	1 quart
	Paradichlorobenzene	$\frac{1}{2}$ pound
	Melted paraffin	$\frac{1}{2}$ pound
LT-30 B	Diesel oil	3 quarts
	Creosote oil	1 quart
	Paradichlorobenzene	$\frac{1}{2}$ pound
LT-31	Water	940 cubic centimeters
	Elgetol	50 cubic centimeters
	Tergitol Penetrant No. 7	10 cubic centimeters
LT-32	Diesel oil	3 quarts
	Cresylic acid	1 quart
LT-33	Kerosene	2 quarts
	Crankcase oil	1 quart
	Creosote	1 quart
	Pyridine	$\frac{1}{2}$ pint
	Melted paraffin	$\frac{1}{2}$ pound
LT-34	Kerosene	2 quarts
	Crankcase oil	1 quart
	Creosote	1 quart
	Trichlorobenzene	$\frac{1}{2}$ pint
	Melted paraffin	$\frac{1}{2}$ pound
LT-35	Kerosene	3 quarts
	Carbolineum	1 quart

LT-36	Carbolineum	
LT-38	Diesel oil	
LT-41	Diesel oil	4 quarts
	Paradichlorobenzene	2 pounds
LT-42	Fuel oil	4 quarts
	Paradichlorobenzene	2 pounds
LT-43	Fuel oil	3 quarts
	Shell aromatic oil No. 2	1 quart
LT-44	Fuel oil	4 quarts
	Orthodichlorobenzene	1 quart
LT-45	Fuel oil	3 quarts
	Shell aromatic oil No. 2	1 quart
	Orthodichlorobenzene	1 quart
LT-46	Fuel oil	4 quarts
	Trichlorobenzene	1 quart
LT-47	Pulp mill liquid (crude sulphate wood turpentine)	
LT-49	Chlorinated toluene (Dupont IN-3102, 50% in water dispersible form).	37 grams
	Water	1 gallon
LT-50	Chlorinated toluene (Dupont IN-3102, 50% in water dispersible form).	74 grams
	Water	1 gallon
LT-51	Water	1 gallon
	Dichlorethyl ether	30 cubic centimeters
	Tergitol Penetrant No. 7	19 cubic centimeters
LT-53	Fuel oil	1 gallon
	Dinitro-ortho-cyclohexylphenol	38 grams
LT-54	Fuel oil	1 gallon
	Dinitro-ortho-cyclohexylphenol	76 grams
LT-55	Water	7 pints
	Parascalecide	1 pint
H-1	Trichlorobenzene 10%—Crankcase oil 90%	
H-2	Orthodichlorobenzene 10%—Crankcase oil 90%	
H-3	Napthalene 10%—Crankcase oil 90%	
H-4	Paradichlorobenzene 10%—Crankcase oil 90%	
H-5	Crankcase oil	
H-6	Shell aromatic oil No. 2	7 pints
	Sulphate wood turpentine	1 pint
	Paradichlorobenzene	$\frac{1}{2}$ pound

H-7	Fuel oil	6 pints
	Sulphate wood turpentine	1 pint
	Cresylic acid	1 pint
	Trichlorobenzene	1/2 pint
H-8	Fuel oil	6 pints
	Sulphate wood turpentine	1 pint
	Creosote	1 pint
	Orthodichlorobenzene	1/2 pint
H-10	Shell aromatic oil No. 2	
H-11	Para-chlor-phenoxy-ethoxy-ethyl-chloride	
H-12	Para-teritary-butyl-phenoxy-ethanol	
H-13	Dichloro-diphenyl-oxide	
H-14	Shell aromatic oil No. 2	6 pints
	Sulphate wood turpentine	1 pint
	Trichlorobenzene	1 pint
H-15	Kerosene	3 quarts
	Ethylene dichloride	1 quart

The sprays used in laboratory experiments were applied with a 1-quart hand sprayer of an improved "flit gun" type, or with an electrically driven, compressed air, paint gun. The sprays used in the field were applied with either a 3-gallon garden sprayer, equipped with oil-resistant hose and fittings, or a 5-gallon knapsack sprayer, with oil-resistant hose and fittings, adjustable nozzle, and agitator (figure 1). The knapsack sprayer was the more satisfactory. All logs were sprayed to the run-off point when single logs were sprayed separately. Piles or stacks were sprayed until the spray on the exposed surfaces reached the run-off point. The amount of spray used per cord of wood varied from 1 to 3 gallons, when an entire pile was sprayed. When individual logs were sprayed, the amount varied from 5 to 10 gallons per cord, depending on the size of the wood. In this method of spraying, the logs received a complete coverage of spray as compared with a partial coverage when sprayed in a pile.

The term "mortality test" is used to refer to experiments in which the sprays were applied to logs which already contained beetle colonies. The object of such experiments was to kill the insects in their galleries, thereby preventing emergence. The expression "mortality test" is used in preference to "toxicity test" because there are several ways in which the treatment could kill without "poisoning". Also, the term includes the mechanical control measures described. Several ways in which a chemical treatment could cause the death of the insects are by desiccation of the bark, either causing it to separate from the wood, exposing the beetles to the air and predators, or causing the bark to dry down

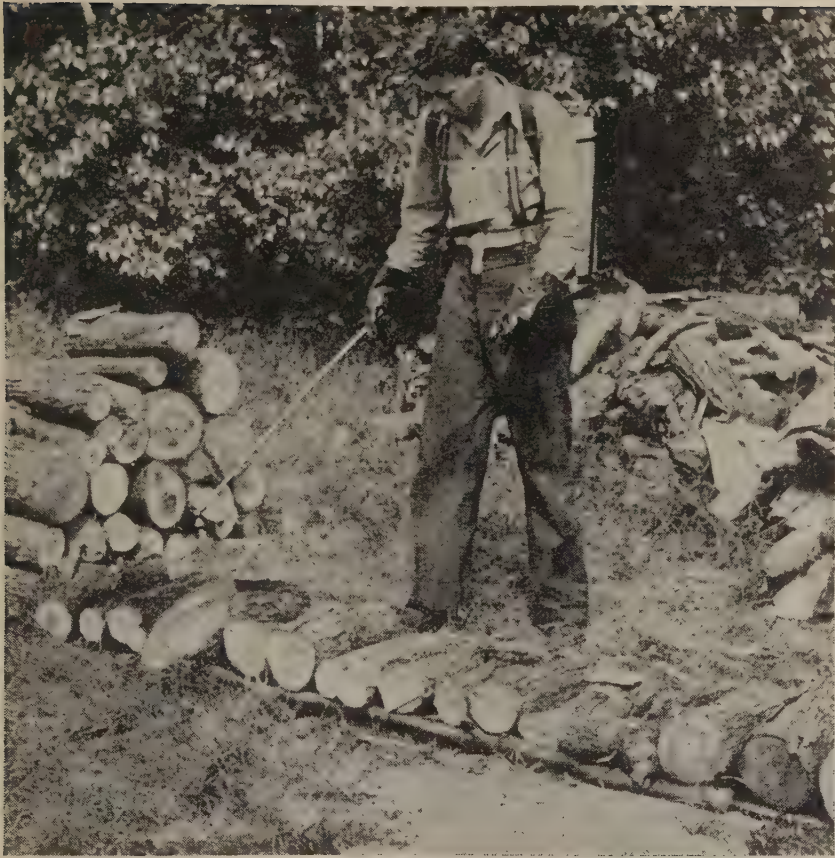


Figure .1. Stovewood lined out, arranged singly. Knapsack sprayer in use.

tightly against the wood; by penetration of poisons into the plant tissues upon which the larvae feed; by penetration of lethal fumes into the brood galleries; by penetration of corrosive materials into the brood galleries; and by suffocation, thru the exclusion of air.

The term "repellency test" is used to refer to experiments in which the chemicals were applied to the logs before infestation, to render them either unsuitable for beetle attack or unsatisfactory for breeding. These effects are obtained by incorporating materials which are distasteful to the beetles, and thus render entry unlikely, or by including materials which cause the bark to dry out quickly, or which leave it impregnated with chemicals which make it unfit for breeding.

Formulae which appeared promising were tested in the field under as many as possible of the conditions under which spraying might con-



Figure 2. Single logs and cut trees.

ceivably be used in practical work. It was considered preferable, therefore, to maintain a large number of groups of tested logs under observation rather than to treat a large number of logs under one set of conditions. The simplest situation would be single logs on the ground (figures 1 and 2), or large broken limbs ("hangers") (figure 3), which could be sprayed singly and completely. More complex than this would be wood piles and stacks, including different sized logs and different methods of piling or stacking (figure 4). Any one of these might occur in a variety of situations, such as on wet ground, in dense shade, in the sun, and so on, with corresponding differences in results. In the tables (tables 1, 2, 3, 4, and 5) these conditions are listed with reference to individual experiments. Expressions used in the tables are explained through the use of footnotes. An expression or descriptive term is explained in this way only where it first appears in the tables. Pertinent facts referring to specific experiments, but not included in the tables, are also presented as footnotes.

At the time the work was begun and for some time thereafter, it was considered incompatible with the control program to allow known beetle sources to exist anywhere in the field. Therefore, field-tested material could not be left in place for emergence and the counting of emergence holes. In most experiments, it was felt that to change the experimental conditions by bringing logs into cages before emer-

gence would introduce a greater error into the interpretation of the results than to rely upon less concise methods of taking the data in the field, such as counting or estimating the living and dead larvae under the bark. These methods are described in detail in the following paragraphs, for each type of experiment.

In all experiments included in the tables, except for five repellency tests which are indicated, comparable check material was used. For instance, a broken limb or a branch on the ground was not sprayed as a test unless there was another similar broken limb



Figure 3. "Hangers" or large broken branches remaining in tree.



Figure 4. Different arrangements of stovewood for spraying. A, single; B, piled; C, stacked; X, stacked in part shade. Except for the stack at X, the wood is all described as in "full sun," being on the south side of the woods, with the grass and weeds cut.

or branch nearby, under the same conditions, which could be left unsprayed as a check. The same procedure was followed with respect to wood piles and every other type of material under all test conditions. If a high mortality occurred in check material in a mortality test, the experiment was considered "no test". In the same manner, for repellency, if no entry or only a few entries occurred in the checks, the experiment was rated "no test".

At the end of a test, the bark was removed from the logs with a hand axe and hunting knife. The top half of logs was usually examined first and a record made of the number of galleries found, the condition they were in, the condition of the larvae found; the approximate ages of the larvae, and whether living or dead eggs, pupae, and callow adults were present. The same procedure was followed with the bottom half of the log. The material in mortality tests was allowed to remain undisturbed until examination of portions of check logs indicated that emergence was imminent.

In the repellency experiments only actual galleries, with or without larval tunnels, were considered in recording data from log examinations. An attempted entry or "touch" which did not result in the construction of a gallery was considered an indication of either initial repellency or a possible latent lethal or repellent effect of the spray on the adult beetle; in either case, the spray prevented the establishment of a gallery. The number of galleries per square foot of bark area examined was used as the unit of comparison. A form of Abbott's formula (Abbott, 1925) was used to calculate the "per cent reduction over the checks", which, for convenience, is here termed the "per cent control". The formula is
$$\frac{ck - tr}{ck} \times 100 = \text{per cent control.}$$
 In repellency

experiments, tr is the average number of galleries per square foot of bark in the treated logs, and ck is the average number of galleries per square foot of bark in the check logs.

In mortality experiments, bark was examined for spray penetration, and the effect of the spray on the bark was noted. This information and visible effect, if any, on the beetles was recorded.

The criterion for judging per cent control in most of the mortality tests was the per cent of living colonies found in the bark of treated logs as compared with the per cent of living colonies in the check logs. The term "colony" as used here refers to all the larvae associated with, or originating from a single maternal gallery. The term "living colony" refers to a colony in which one or more larvae were alive and apparently healthy. These percentages were usually based on definite counts, occasionally on estimates. All percentages derived from estimates are so indicated in the tables.

When percentages of control were calculated in the usual way, the

terms of Abbott's formula were used with *ck* as per cent living colonies in the check logs; and *tr* as per cent living colonies in the treated logs.

Where it was possible to allow the beetles to emerge, in cage tests and a few field tests, the number of emergence holes was counted, as well as the number of galleries, and the average emergence per gallery was calculated. The terms of the formula were then used as follows: *ck*: average emergence per gallery in the check logs; *tr*: average emergence per gallery in treated logs.

Since the data obtained by the methods described give figures which are relative rather than exact, it is particularly important to consider each test in relation to all the others. This applies to those tests in which emergence holes were counted, as well as to the others. To assist in determining the relative weight to be given to data from different tests, the number of tests, the number of square feet of bark examined, and the number of colonies of beetles observed must be considered, in addition to the proportions of colonies which survived or the number of beetles which emerged. These figures are all given in the tables under appropriate headings. Since it is the number of galleries containing living insects that were counted, not the number of surviving insects themselves, the odds, in the percentage of control, are strongly against the control measures. It is believed, for this reason, that the data given are more likely to reflect kill actually due to the control measures involved than would percentages based on counts of actual numbers of living and dead larvae, since there are many natural factors that can cause a high mortality.

The figures in the column headed "number of galleries observed" refer to the sprayed material alone. Experiments in which the check material did not furnish comparable data in this category are not included. Since the data from the checks are used in calculating the percentages of control, they are not listed separately in the tables.

Although the figures refer chiefly to *Scolytus multistriatus*, in the few instances where *Hylurgopinus rufipes* galleries occurred in the same log, no distinction is made because spray effect on both species is apparently the same. The mortality tests included in this bulletin involved larvae of all ages. Prepupae and pupae appeared to be more difficult to kill. Perhaps one reason for this is the comparatively short time during which the sprays can affect them. Also, if penetration of lethal liquids or fumes is by diffusion through entrance holes, and into larval tunnels from the maternal tunnel, the older the larva is, the farther the liquid or fumes must travel. In general, larvae in the bark not wet by the sprays were not killed.

Results. Tables 1, 2, 3, 4 and 5 were composed in such a way as to answer the questions, (1) What can be expected of any formula or

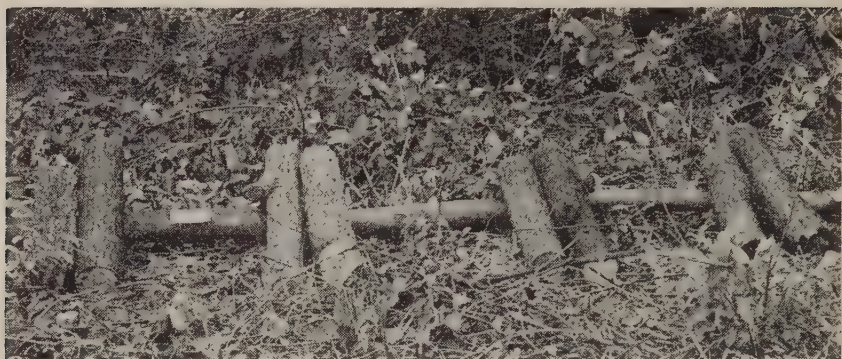


Figure 5. Logs grouped, lined out.

method under various conditions; and (2) Which formula or method worked best, and under what conditions?

To answer the first question, with respect to a mortality test, the table (table 1) is entered at the first line of any formula, taking LT-29 as an example. By proceeding down and across, the following information is found: With partial coverage of logs in the sun in the summer, there was apparently good control in one test, but the number of



Figure 6. Logs in large cage, stacked.



Figure 7. Logs in pyramid formation.

beetle galleries was so small that little significance can be attached to it. (The data presented from more extensive tests of other formulae indicate that control could not be expected under such conditions). The tests run in the spring on several types of logs produced unfavorable results, even when complete spray coverage of each log was obtained and the logs were stored in the sun. When the test was run in the summer, however, complete coverage of wood of stovewood size, subsequently stacked in the sun, gave a good control.

To answer the second question, a convenient method is to select in the table all the high percentages of control, and then to read to the left and to the right to see what conditions were involved in any instance. At the same time, it can be noted whether the data which contributed a percentage were numerous or few, and the value of the tests can be weighed accordingly. Instances of percentages based on insuffi-

Table 1. Synopsis of mortality tests of log sprays.
(A) Field tests.

*Formula	†Test period	Type of wood and ‡ method of arrangement	§Per cent control under conditions of:						**Num-ber of tests	Square feet bark exam-ined	Number galleries observed	Per cent galleries with sur- viving †† beetles
			Partial spray coverage			¶Complete spray cover- age						
			Sun	Part Shade	Shade	Sun	Part Shade	Shade				
LT-1A	summer	stovewood; stacked	..	..	..	100	..	..	1	5	34	0
LT-2	summer	stovewood; stacked	0	..	..	..	..	..	2	7	49	96
LT-7	summer	stovewood; stacked	15	..	..	..	..	..	1	7	12	67
LT-10	winter	logs; stacked	..	..	..	..	0	..	1	18	81	100
LT-29	spring	logs; stacked	20	..	..	..	..	..	1	37	..	(76)
LT-29	summer	stovewood; stacked	100	..	..	..	..	..	1	3	2	0
LT-29	summer	logs; single	..	26	..	..	..	..	2	54	133	23
LT-29	summer	logs; single	..	..	9	..	..	..	1	52	121	53
LT-29	spring	logs; single	..	..	..	8	..	..	2	47	..	(87)
LT-29	spring	logs; stacked	..	..	..	12	..	..	1	54	..	(84)
LT-29	summer	stovewood; stacked	..	..	..	100	..	..	1	8	41	0
LT-29	summer	hanger	..	..	..	..	..	64	1	14	11	36
LT-30	summer	stovewood; stacked	21	..	..	..	..	..	5	29	169	62
LT-30	summer	logs; single	11	..	..	..	..	..	1	14	91	32
LT-30	summer	logs; single	..	0	..	..	..	..	1	10	51	49
LT-30	summer	logs; single	..	..	47	..	..	..	1	12	13	31
LT-30	spring	logs; stacked	..	..	..	62	..	..	1	29	..	(25)
LT-30	summer	stovewood; single	..	..	..	100	..	..	1	4	6	0
LT-30	summer	stovewood; stacked	..	..	..	100	..	..	1	8	39	0
LT-30	summer	hanger	..	..	..	..	98	..	1	15	52	2

LT-30	summer	logs—pyramid form	..	..	..	0	..	..	1	7	212	100
LT-30	fall	logs; stacked	..	..	..	65	..	..	1	14	328	(35)
LT-30B	summer	logs; stacked	..	..	..	67	..	..	1	19	478	32
LT-31	summer	logs; stacked	..	..	..	7	..	..	1	16	452	90
LT-32	spring	logs; stacked	..	..	..	44	..	..	1	5	56	..††
LT-33	spring	branch on ground	..	..	..	..	..	..	1	25	..	(96)
LT-33	spring	logs; stacked	..	..	..	..	0	..	1	50	..	(94)
LT-34	summer	stovewood; stacked	63	..	..	..	..	..	1	7	7	29
LT-34	summer	logs; single	47	..	..	..	..	..	1	43	214	19
LT-34	summer	stovewood; stacked	..	59	..	..	..	..	1	5	5	40
LT-34	summer	logs; single	..	0	..	..	..	..	1	26	47	38
LT-34	summer	logs; single	..	..	..	..	..	..	1	70	360	53
LT-34	summer	stovewood; stacked	..	..	9	..	100	..	1	10	129	0
LT-34	summer	hanger	..	..	..	96	..	..	1	14	23	4
LT-35	summer	stovewood; stacked	..	..	..	87	87	..	1	4	20	10
LT-36	summer	stovewood; stacked	..	..	..	24	24	..	1	5	5	60
LT-38	summer	stovewood; piled	100	..	..	..	..	..	1	2	2	0
LT-44	summer	logs; stacked	..	0	..	..	..	..	1	27	282	91
LT-44	summer	logs; stacked	..	..	..	84	84	..	1	27	1,648	10
LT-45	summer	logs; stacked	..	0	..	..	..	..	1	23	701	98
LT-46	summer	logs; stacked	46	..	..	..	..	..	1	14	159	54
LT-47	summer	stovewood; stacked	..	..	..	99	..	..	1	21	1,287	0.4
LT-49	summer	logs; stacked	27	..	..	..	..	..	1	6	29	66
LT-50	summer	logs; stacked	..	0	..	..	..	..	1	6	51	100
LT-51	summer	logs; stacked	..	0	..	..	..	..	1	6	31	100
LT-53	summer	logs; stacked	..	..	..	39	..	..	1	18	404	59
LT-54	summer	logs; stacked	..	..	..	85	..	..	1	18	238	14
LT-55	winter	logs; stacked	..	..	..	20	20	..	1	16	251	80
H-1	spring	stovewood; stacked	..	..	..	81	..	..	1	(13)	94	..††
H-2	spring	stovewood; stacked	..	..	..	67	..	..	1	(13)	115	..††

Table 1.—Concluded.

*For- mula	†Test period	Type of wood and ‡ method of arrange- ment	§Per cent control under conditions of:							**Num- ber of tests	Square feet bark exam- ined	Number galleries observed	Per cent galleries with sur- viving †† beetles
			Partial spray coverage			¶Complete spray cover- age							
			Sun	Part Shade	Shade	Sun	Part Shade	Shade					
H-3	spring	stovewood; stacked	..	..	..	..	40	..	1	(13)	107	.. ††	
H-14	spring	logs; stacked	..	..	..	..	47	..	1	5	64	.. ††	
H-14	summer	logs; stacked	..	..	..	..	68	..	1	(6)	84	31	
H-15	summer	logs; grouped	..	..	..	..	85	..	1	(6)	114	15	

*Formula numbers refer to the list of formulae on pages 7-10.

†The test periods were as follows: *Summer*: June, July, August; *Fall*: September and October; *Winter*: November, December, January and February; *Spring*: March, April and May. The tests were always begun in the period specified, and the logs were usually examined toward the end of the same period.

‡Type of wood. *Stovewood*: Pieces of wood 16 to 20 inches long and 4 to 8 inches in diameter, as in figure 4. *Logs*: Logs 2 feet to 6 feet long, usually 4 to 6 feet, as in figure 6. *Hanger*: Large broken branch or dead limb remaining in tree, 6 inches to 12 inches in diameter, as in figure 3. *Dead branch on ground*: A branch or small cut tree; distinguished from a "log" by fact that side branches, and sometimes, foliage were not cut off, as in figure 2. *Method of arrangement*. *Stacked*: Piled in a regular fashion, as in figure 4(C). *Piled*: Piled in irregular fashion, as in figure 4(B). *Single*: Single logs, separated, not in groups as in figure 4(A). *Pyramid form*: Logs stood on end in a wide circle with upper ends leaned against one another, as in figure 7. *Grouped*: Arranged in a single layer but in groups of 2 or more logs, as in figure 5.

The methods of arrangement listed are the methods used after spraying. Thus, logs might be sprayed separately, and then stacked, the latter term appearing under "method of arrangement". The conditions of spraying are described in the columns headed "per cent control".

§Per cent control. The per cent reduction over the checks; from Abbott's formula, as described on page 14.

||Partial coverage. Describes the condition of logs or groups of logs sprayed without moving them, that is, on exposed surfaces only. Includes logs sprayed in piles or stacks, and logs on the ground which were sprayed without being turned.

¶Complete coverage. Describes the condition of logs which were sprayed individually, with care taken to cover all sides with spray to the run-off point.

**Number of tests. The number appearing in this column refers to the number of tests with each formula made under the exact conditions specified. Thus, of the 10 tests with formula LT-30, only one was made with separated logs under conditions of partial coverage in the sun in the summer, but 5 tests were made with stovewood stacked in the sun, with partial coverage, in the summer. In the latter instance, the figures for the 5 tests were totaled, since all the tests were under approximately the same conditions.

††Per cent of galleries with surviving beetles. See page 14 for further information. The term "beetles" as used here refers to beetles in any stage of development.

()Numbers in parentheses are based on estimates. All others were determined by actual counts.

‡‡Average emergence per gallery, instead of the per cent of galleries with living beetles, used to calculate per cent control.

cient data can then be either discarded or considered in relation to other tests of a similar nature to determine whether the accumulated volume of data reaches a point where a valid judgment seems permissible.

A given term, expression or usage in any one table, or common to several tables, for which a footnote is furnished, is explained only where it first appears.

Summary of mortality tests. Refer to tables 1 and 2. Of the 61 tests listed in table 1, there are only 15 in which the percentage of control is 75 per cent or higher. Of these, 3 tests were based on counts of under 20 colonies and are not regarded as important. The remaining 12 were all tests where the logs had been sprayed completely and separately; all but one were summer experiments³; all were either in full sun or part shade. The formulae included in these 12 tests were LT-1A, 29, 30, 34, 35, 44, 47, 54, H-1, and H-15. Of these, LT-29, LT-30, and LT-34, having been promising from the beginning, received the greatest number of trials, under the widest variety of conditions. These were all similar formulae, being composed of a light fuel oil base in which were mixed creosote and a fumigant of the naphthalene or chlorobenzene type, and were not definitely distinguishable from one another in their effects. One summer test with LT-30 under apparently favorable conditions gave no control, but in this test, the insects were all in the prepupal and pupal stages.

Of the other formulae that appeared promising under favorable conditions, one was "pulp mill liquid" (LT-47). This was described as a "crude sulfate wood turpentine", a by-product or residual product of paper-making. This produced a 99 per cent kill in part shade, in a test involving more than a thousand galleries. "Pulp-mill liquid" has a strong, pungent, disagreeable odor which soon disappears but leaves a persistent residual odor of turpentine. LT-1A and LT-35 both had a kerosene base, to which was added a creosote type of chemical (creosote in the former case, carbolineum in the latter). LT-44 and H-1 were also similar in that they had an oil base, although the latter was crankcase oil. LT-44 was the same as one of the best formulae used by Whitten (1942). The remaining two formulae (LT-54 and H-15) were both light oils but with dissimilar chemicals added. Refer to pages 9-10 for ingredients.

In the comparison of sprays composed of a light oil and a creosote (LT-1A and LT-35) with those made up of a light oil and a fumigant (LT-44, H-15) little difference in mortality effect could be noted, although it appeared that the most consistent results could be expected

³ The one exception was an experiment which was begun in the greenhouse and concluded outdoors. It is not considered a typical test, since beetles continuously bred in the greenhouse may be affected by the sudden change in conditions when they are placed out of doors.

Table 2. Synopsis of mortality tests of log sprays.
(B). Laboratory tests.

Formula	Test period	Type of wood and method of arrangement	Per cent control under conditions of:						Num-ber of tests	Square feet bark exam-ined	Num-ber galleries observed	Per cent galleries with sur- viving beetles
			Partial coverage		Complete coverage							
			*Out-door cage	†Green-house	‡In-side	Out-door cage	Green-house	In-side				
LT-7	spring	stovewood; single	..	..	..	..	..	39	4	..	(60)	
LT-8	spring	stovewood; single	..	..	..	..	..	4	3	..	(94)	
LT-13	spring	stovewood; single	..	..	..	..	..	8	4	..	(90)	
LT-18	spring	stovewood; single	..	..	..	..	..	8	3	..	(90)	
LT-24	spring	stovewood; single	..	..	..	..	..	49	3	..	(50)	
LT-19	fall	logs; grouped	..	..	..	99	..	..	27	114	1	
LT-30	spring	stovewood; single	..	..	..	100	..	..	8	153	(0)	
LT-30	summer	logs; stacked	..	..	..	99.9	..	..	29	1,676	0.1	
LT-31	spring	stovewood; single	..	..	..	84	..	..	9	148	(15)	
LT-32	spring	stovewood; single	..	..	..	94	..	..	10	260	(6)	
LT-44	spring	logs; stacked	48	..	..	..	..	..	53	1190	52	

									Average emergence per gallery
H-1	spring	stovewood; grouped	..	..	12	..	2	(6)	118
H-2	spring	stovewood; grouped	..	..	30	..	2	(6)	150
H-3	spring	stovewood; grouped	..	..	10	..	2	(6)	148
H-4	spring	stovewood; grouped	..	..	36	..	1	(5)	140
H-5	spring	stovewood; grouped	..	..	0	..	1	(5)	84
H-6	spring	stovewood; grouped	..	..	65	..	1	(6)	92
H-7	spring	stovewood; grouped	..	..	50	..	1	(6)	80
H-8	spring	stovewood; grouped	..	..	51	..	1	(6)	71
H-9	spring	stovewood; grouped	..	..	0	..	1	(6)	156
H-10	spring	stovewood; grouped	..	..	32	..	1	(6)	53
H-11	spring	stovewood; grouped	..	..	85	..	1	(6)	147
H-12	spring	stovewood; grouped	..	..	83	..	1	(6)	131
H-13	spring	stovewood; grouped	..	..	82	..	1	(6)	144

*Outdoor cage; described on page 28.

†Greenhouse; An ordinary greenhouse kept at a high humidity and a temperature of 70 to 80° F.

†Inside: A room in the basement of the laboratory, described on page 24.

when both the chlorobenzene or other fumigant and creosote or carbolineum were added. Whether one or the other of these was more essential did not appear in the data. With the heavy oils, only the formula with trichlorobenzene (H-1) gave results comparable to those obtained with light oils.

A consideration of the conditions under which the tests were made shows that only in summer tests, in which the logs were completely covered with spray and subsequently stored in the sun, could favorable results be reasonably expected even with the best of the sprays studied. If these conditions were met, within the limits of the tests, it made no difference whether the logs were large or small, or stacked, piled, or separated (that is, a "hanger," or a single log on the ground). There is no evidence that any of the sprays used can be improved so as to be satisfactory under other conditions, except possibly through a combination of spraying with mechanical measures such as scoring, as described in later paragraphs. Salman (1938) states that bark which has been hacked, scored, or perforated can absorb more oil than sound bark, and it seems logical that such treatment would cause a higher or more certain mortality.

In general, it seemed to be true that when the bark was wet, especially if it had been thoroughly soaked, oil sprays did not penetrate well and did not kill. Bark is frequently in such a state during the winter and spring. This fact, and the low temperatures prevalent during these periods, are perhaps the chief reasons winter and spring spray treatments were not successful. Whitten (1942) stated that bark moistures of from 30 to 139 per cent did not significantly affect the results of his better formulae. Salman (1938) and Franzen (1939) both found that a high moisture content was definitely unfavorable. Salman suggested that the drying out of phloem and bark which occurs gradually with the development of the broods (of pine bark beetles) favors the spread of oil and counteracts the greater resistance of the older larvae. Salman, Franzen, and Whitten agree that low temperatures such as occur during winter and spring definitely limit the effectiveness of oil treatments.

Tests which were carried out indoors or in large cages out-of-doors are listed in table 2. They were, for the most part, tests made during winter and early spring. Some of the tests were preliminary trials of materials to be tried later in the field. Others were supplementary tests, to shed further light under more easily controlled conditions, on questions resulting from field tests. For the tests listed in the column headed "Inside", a cage 12 feet long by 6 feet wide by 6 feet high was set up in a large basement room, and the beetle-infested logs were placed in this cage from winter breeding cages in the greenhouse. The room had no windows; air circulation and ventilation were obtained with an electric fan. The room was kept at a temperature of 73 degrees F. and

Table 3. Synopsis of repellency tests of chemical log sprays.
(A) Laboratory tests.*

For- mula	Test period	Type of wood and method of arrangement	Per cent control under conditions of:						Num- ber galleries ob- served	Square feet bark ex- am- ined	Num- ber galleries per square foot bark
			Partial coverage			Complete coverage					
			Out- door cage	Green- house	In- side	Out- door cage	Green- house	In- side			
LT-7	March 8-April 23	stovewood; single	..	..	..	...	..	100	4	0	0
LT-8	March 8-April 23	stovewood; single	..	..	..	...	..	98	4	3	0.8
LT-13	March 8-April 23	stovewood; single	..	..	..	...	..	100	4	0	0
LT-18	March 8-April 23	stovewood; single	..	..	..	...	..	100	4	0	0
LT-24	March 8-April 23	stovewood; single	..	..	..	...	..	100	4	0	0
LT-44	May 14-August 3	logs, stacked	97	..	..	...	..	...	16	28	2
LT-19	August 28/41-May 13/42	logs; grouped	..	..	..	100	...	...	17	0	0
LT-2	August 15-September 9	stovewood; piled	†99	..	..	...	..	...	41	3	0.70
LT-30	July 19-October 7	logs; stacked	..	..	..	†100	..	...	38	0	0

*In laboratory repellency tests, beetles were released in cages containing the logs, the numbers of beetles used depending on the amount of wood included in the test. Additional notes on pages 28 and 29.

†No check logs used in the tests indicated.

Table 4. Synopsis of repellency tests of chemical log sprays.
(B) Field tests.

For- mula	Test period	Type of wood and method of arrangement	Per cent control under conditions of						Num- ber of tests	Square feet bark exam- ined	Number galleries ob- served	Average number galleries per square foot bark
			Partial coverage			Complete coverage						
			Sun	Part shade	Shade	Sun	Part shade	Shade				
LT-1	June 16-August 31	stovewood; stacked	...	...	...	100	...	...	1	13	0	0
LT-1	June 26-September 19	stovewood; single	...	...	...	...	100	...	1	5	0	0
LT-2	June 26-September 19	stovewood; single	...	...	...	...	100	...	1	5	0	0
LT-2	July 24-September 28	stovewood; single	...	...	...	...	30	...	1	3	34	11
LT-2	July 25-September 27	stovewood; stacked	...	...	...	...	75	...	1	7.5	114	15
LT-2	July 24-September 28	stovewood; stacked	...	...	...	...	97	...	1	12	7	0.6
LT-2	July 24-September 28	stovewood; single	...	...	...	...	...	100	1	3	0	0
LT-2	July 24-September 28	stovewood; single	...	...	...	49	...	...	1	4	52	13
LT-2	July 28-September 11	stovewood; piled	*100	*100	*100	...	...	...	3	203	0	0
LT-2A	July 25-September 27	stovewood; stacked	...	...	...	...	90	...	1	8	49	6
LT-2A	July 24-September 28	stovewood; stacked	...	...	...	...	99	...	1	13	2	0.2
LT-2A	July 24-September 28	stovewood; single	...	...	...	...	8	...	1	4	48	13
LT-2A	July 24-September 28	stovewood; single	...	...	...	...	...	79	1	3	1	0.4
LT-2A	July 24-September 28	stovewood; single	...	...	...	81	...	...	1	4	18	5
LT-3	June 26-September 19	stovewood; single	...	...	...	...	78	...	1	5	14	3
LT-4	June 26-September 19	stovewood; single	...	...	...	...	97	...	1	5	2	0.4
LT-5	July 25-September 27	stovewood; stacked	...	...	...	...	58	...	1	5	134	25
LT-9	October 14-June 19	7 inch felled tree	...	...	...	...	100	...	1	12	0	0
LT-10	October 14-June 19	7 inch felled tree	...	...	...	...	100	...	1	12	0	0

LT-19	October 14-June 19	7 inch felled tree	...	...	...	100	...	1	9	0
LT-29	August 8-October 17	logs; single	...	0	...	...	...	1	48	11
LT-30	August 21-July 23	logs; pyramid form	...	...	...	86	...	1	7	43
LT-30	October 14-June 19	7 inch felled tree	...	...	...	100	...	1	12	0
LT-30	August 21-August 6	logs; pyramid form	...	...	...	95	...	1	7	4
LT-30	March 28-June 20	logs; stacked	...	81	...	...	...	1	34	452
LT-38	April 16-June 23	logs; stacked	87	...	...	...	...	1	48	181
LT-41	April 15-June 25	logs; stacked	...	...	...	87	...	1	28	260
LT-42	April 16-June 25	logs; stacked	...	...	...	94	...	1	27	110
LT-43	April 16-June 23	logs; stacked	93	...	...	...	...	1	31	58
LT-44	June 10-July 25	logs; stacked	75	...	...	...	...	1	23	70

*No check logs used in the tests indicated.

humidity 80 per cent. Early tests indicated that crankcase oil, undiluted, was, in general, not a good base for a spray. Later tests, out-of-doors, showed that it could be substituted for about $\frac{1}{3}$ of the lighter oil, as in LT-34.

In the outdoor cage (figure 6), the wood was in sunshine modified by a framework of lath slats over the top of the cage. The cage was 18 feet long by 14 feet wide by 8 feet high. Since the shade of slats was about 8 feet above the ground, the wood received direct sunlight through the sides of the cage, filtered only by the screen. In these experiments, formula LT-30 was included to test further the impression already gained from field tests that it would give a fairly good control. It gave equally good results in the cage tests.

Cage tests, however, were not always reliable as an index of what can be expected in the field. For instance, LT-31 (an elgetol formula) gave a fairly high control in the cage, but seemed very poor in the field, and the same was true of LT-32 (cresylic acid in diesel oil). Of the formulae tested in the greenhouse on a small scale, H-11, H-12 and H-13 were considered promising, but were not tested in the field. They were three of the materials found best by Christian (1940) for prevention of damage by Ambrosia beetles.

Summary of repellency tests. Refer to tables 3 and 4. Preliminary tests for repellency on uninfested logs and later tests run to confirm the results of field experiments were made in the large out-door cage and also in the basement room described above. The tests are listed in table 3. In these tests, beetles were released and allowed a choice of entering sprayed or check logs, except in the tests of LT-2 and LT-30, in which no check logs were used. In the basement room, virtually a 100 per cent repellency was obtained with several crankcase oil formulae, but these mixtures were too heavy to be practical for field use.

LT-44 and LT-19 in the large cage out-of-doors gave virtually 100 per cent repellency. The cage tests with LT-2 and LT-30, as stated, did not include check logs. In the former test, 2,300 specimens of *Scolytus multistriatus* were introduced over a period of a week with only 3 colonies becoming established. In the test with LT-30, 2,500 specimens of *S. multistriatus* were introduced on one day. No entries occurred. The per cents of control were arbitrarily called 99 per cent and 100 per cent respectively.

From table 4, which lists the field tests for repellency, it would seem that repellency may be brought about by a wider range of materials than is mortality, but that there is wide variation in repellency of a given formula under similar conditions. It is evident, further, that repellency occurred with material sprayed in the fall and spring, as well as with material sprayed in the summer, and that partial coverage of material stored in the shade was sometimes effective. This may be

partly due to the fact that wood in such a situation usually attracts fewer beetles (*Scolytus multistriatus*), even when left untreated, than wood in sunny locations.

The same types of mixtures that were most effective in causing mortality were also effective as repellents, namely light petroleum oils containing varying amounts of creosote, turpentine, and fumigants. However, there was evidence that simpler mixtures were also effective, and it is probable that a formula such as LT-1 (creosote and kerosene) is just as good as those containing a chlorobenzene. Repellency depends on a number of factors not involved when mortality alone is concerned. It may vary with the same formulae according to the number of beetles in the vicinity and the amount of untreated attractive material favorably located nearby, which could account for much of the variation in effectiveness of the same or similar formulae which appears in table 4.

The repellency of the oil-creosote mixtures appears to be permanent, since a log sprayed with LT-2 was not entered the second year after spraying. In general, a log that has remained free from attack for a season is no longer suitable for successful bark beetle breeding. In many instances, sprayed logs have been invaded by insects such as *Saperda tridentata*, which in itself would help to render the log unsatisfactory for bark beetles.

II. TESTS OF MEASURES OTHER THAN SPRAYING

Studies of the biologies of elm bark beetles have brought to light a number of features of their habits and life histories which could conceivably be utilized in such a way as to reduce their numbers, and in specific instances, to prevent infestation of certain logs or to bring about high mortality in logs already infested. The work of F. C. Craighead and his associates on the control of bark beetles in western forests (Craighead and associates, 1931, and separate papers by the same authors) has been so comprehensive that their findings have influenced all subsequent work in this and related fields, including the control of elm bark beetles. As pointed out in the paper cited, "Each species of bark beetle presents its own special problems, and must be dealt with differently from other species as to control methods and strategy, and even the same species may present problems which differ in different regions". Thus, *Hyluopinus rufipes* and *Scolytus multistriatus* differ widely in their habits and life histories, and although the findings on chemical sprays may be applied, in general, to both species, the mechanical measures and biological factors studied usually apply more specifically to one species. For instance, *S. multistriatus* finds, enters, and survives best in freshly cut elm wood in locations where it receives sunlight during certain periods of the day. If the wood is

continuously damp and heavily shaded it is not readily entered. *H. rufipes* readily enters and breeds in more heavily shaded material, so that wood protected from *S. multistriatus* by shading is not protected from *H. rufipes*. However, the period of heaviest flight of first brood *S. multistriatus* is later in the spring than that of hibernating *H. rufipes*, and heaviest flight of the second brood *S. multistriatus* occurs when the majority of *H. rufipes* specimens are seeking winter quarters, not breeding places. Thus, wood in shade in early spring is not protected from *Hylurgopinus* entry, whereas wood cut and left in dense shade after July first is more likely to remain free from attack by both species until it can be otherwise treated. Shaded wood that dies or is cut late in the season may not be attacked by *S. multistriatus* the same year but may be subject to invasion by *H. rufipes* the following spring.

Becker (1940) recorded a mortality as high as 100 per cent in *Hylurgopinus rufipes* larvae occurring in the upper half of logs exposed to the sun, although emergence occurred from the under sides of such logs and from all sides of logs in the shade. In one series of tests (1937), he recorded subcortical temperatures as high as 122 degrees F. in logs in the sun.

It would be very convenient to be able to take advantage of such factors as intolerance to high temperatures or desiccation, or susceptibility to dampness and mold, in devising "natural" control measures; in other words, to be able to effect or encourage conditions so unfavorable that survival of the beetles is reduced to a minimum. Tests of measures of this kind, and of more artificial measures such as fumigation, are summarized in table 5.

Materials and methods. (Roman numerals refer to the corresponding sections in table 5). I. Hay Coverage. A thick layer of hay was placed over the log piles so as to cover all logs completely. The piles consisted of stovewood piled informally in the first experiment, and 5-foot logs stacked in the second. The hay was matted down to a thickness of about 3 to 6 inches and weighted with sticks (figure 8).

II. Mechanical Injury. Logs in these experiments were treated in various ways as follows:

- (a) Scoring: the blade of an axe was driven into the log diagonally, resulting in a cut or gash through the bark and into the sapwood. These cuts were made at 4-inch intervals over the entire surface (figure 9).
- (b) Pounding: the back of a single-bitted axe was used for this operation. The blow was given in such a manner as to bruise the bark and sometimes to break it. This was done at 4-inch intervals over the entire surface.

III. Hot water. Tests with this method were carried out in the greenhouse. Hot water was drawn from the tap with the use of a garden hose and run into a standard-size ash can. Logs to be tested were placed

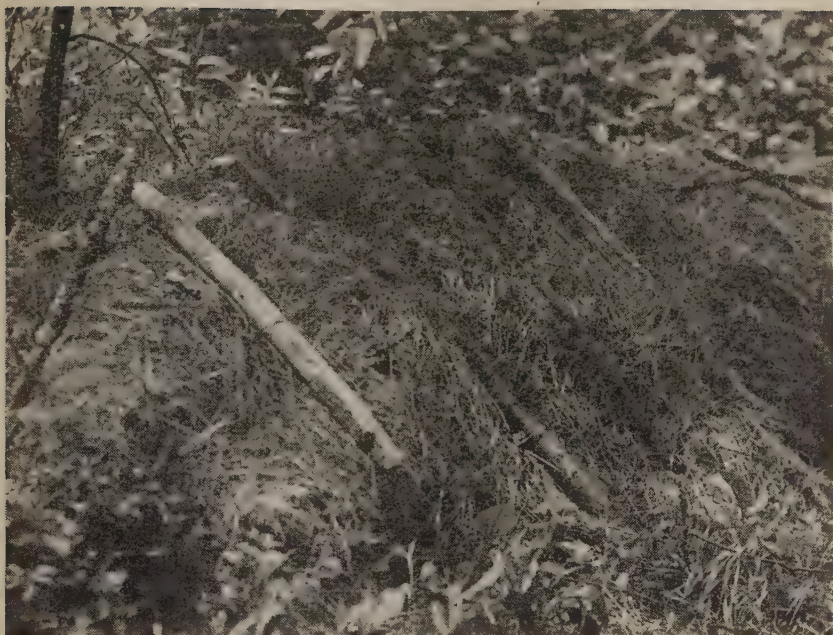


Figure 8. Logs covered with hay.

in the ash can before the water was run into it, and held down with a weight. The temperature of the water in the first test immediately after it was run into the container was 127 degrees F.; in the second test,



Figure 9. Scored or gashed logs and pounded logs.

137 degrees F. These tests were tentative, and additional temperature readings were not made.

IV. Flame. The flame was produced by a weed-killer blow torch, which gave a flame 30 inches long and 2 to 3 inches in diameter. This flame was stated to produce a temperature of 2000 degrees F. Kerosene was used as fuel in a 3-gallon garden sprayer type of fuel tank, with pressure guage attached. Pressure maintained was 35 to 45 pounds. The flame was played back and forth over the surface of the bark for a total of not more than five minutes for the entire log (figure 10).

V. Sun exposure. Logs given this treatment were placed in the open, where the direct rays of the sun would strike them during the hottest part of the day, that is, during the late morning and early afternoon. Care was taken to see that the sides of the logs were not shaded by grass, weeds, or other logs. Logs that were not rolled remained in one position throughout the test. Those that were rolled were given a quarter turn after 3 or 4 days of sun exposure so that a new quarter of the log would be uppermost and exposed to the direct rays of the sun. This process was repeated until each quarter of each log had received



Figure 10. Weed-killer blow torch used to scorch logs.

full sun exposure for several days. The days of sun exposure were not always consecutive, since cloudy days were not included as parts of the exposure period.

VI. Live Steam. In each test the pile of logs was covered with a tarpaulin, and the steam was piped into the center of the pile (figure 11). In the first tests, the steam was piped from the boiler of the heating



Figure 11. Logs subjected to steaming.

plant at the laboratory for half an hour. In the other tests, the steam was generated in a portable boiler heated by the blow torch used in the flame experiment (figure 12). In each test, the flow of steam into the center of the covered piles was maintained for half an hour.

VII. Fumigation. Logs were stacked, and covered by a heavy tarpaulin. The cubic contents of the enclosed space was estimated, not allowing for the space taken up by the wood. The tarpaulin was held down firmly all around the stack with 6-inch logs to prevent leakage of fumes. The fumigants used were as follows:

1. Chloropicrin. The material used was sold under the name of "Larvacide," by Innis Speiden and Co., New York. According to the label, it contains 99 per cent chloropicrin. This was poured into a piece of cheesecloth inserted in the center of the stack, at the rate of 1 pound per 1000 cubic feet of space. This dosage is recommended by



Figure 12. Portable boiler used in the field in steam tests.

the manufacturer for warehouse fumigation against "weevil, moth, and similar insects". The stack remained covered for eight days.

2. Calcium Cyanide. The material used was "Cyanogas G-Fumigant," which contained 42 per cent calcium cyanide, according to the label. This was used at the rate of 3 pounds per 1000 cubic feet of space and was sprinkled among the logs in the stack. Two pounds per 1000 cubic feet is the recommended dosage for mill fumigation. The stack remained covered with the tarpaulin for eight days.

3. Paradichlorobenzene. The crystals were sprinkled among the logs in the pile at the rate of 5 pounds per cord of wood. (When used in sprays, the proportion was $2\frac{1}{2}$ to 10 pounds per cord of wood). The logs were cut up into stovewood lengths and piled in an informal manner on the ground. After the application of the paradichlorobenzene crystals, the pile was covered with a thick matting of hay which was weighed down with sticks and allowed to remain all winter.

VIII. Biological Control. The entomogenous fungus *Beauveria* sp., probably *bassiana* (Bals.) Vuill., was reported by Rex (1940) to be fatal to adult Japanese beetles and to be capable of transmission from one insect to another by contact. Preliminary tests in our laboratory indicated that both species of elm bark beetles were probably readily susceptible to this fungus, and it was suggested that if conditions favorable to the growth of the fungus could be encouraged in a wood pile, a considerable mortality of bark beetles might result. It is even conceivable that some degree of actual control of beetle breeding might be achieved through the manipulation of this fungus. Many factors in the biology of the fungus and its relationship to the beetles are involved and are not well understood. Experiments thus far completed do not furnish any basis for positive statements.

The following paragraphs contain explanatory and descriptive notes applying to the items in table 5.

Symbols: *BI* indicates beetle infested wood, which was used in mortality tests. *NB* indicates "no beetles", or uninfested wood used in repellency tests. Occasionally, data were obtained on both repellency and mortality in the same experiment. In the tests listed in table 5, all the bark on every log was examined.

Size of wood: Items 4 through 20; 27, and 29 were logs 4 to $4\frac{1}{2}$ feet long and 4 to 8 inches in diameter. Items 21 through 26 were "stovewood", that is, pieces 16 to 20 inches long and 4 to 6 inches in diameter. Item 28 included 6-foot logs.

Amount of wood: Items 4-7: 1 log under each condition; total of 16 logs. Items 8-11: 4 logs under each condition; total of 16 logs. Items 12-15: 1 log for each item. Item 16: 10 logs. Items 17, 18, 19: 9 logs each. Item 20: 5 logs. Items 21-24: 4 logs in each item. Items 25-26: 3 logs each. Item 27: 1 log. Items 28-29: 2 logs each.

**Starred Items:* Number 2. The gallery noted was *Hylurgopinus rufipes*. Items 4 through 11 comprised a total of 16 logs. The logs described in items 8 through 11 were the same logs as those in item 4 through 7. They are listed twice in the table to afford comparison (1) on the basis of treatment (items 4 through 7) and (2) with the data rearranged so that they may be compared on the basis of location (items 8 through 11).

Table 5. Synopsis of log treatment tests other than spraying.
(For explanatory notes see preceding paragraphs)

Item number	Treatment	Test period	Per cent control		Square feet bark area examined	Number galleries observed
			Repellency	Mortality		
I. HAY COVERAGE						
1	(NB) stovewood, 1/8 cord, on ground, cov. w. hay	August 22-June 16	100	...	7	0
2*	(NB) stovewood, same pile, second examination	Aug. 22/41-Dec. 4/42	98	...	6	1
3	20 5-foot logs. BI, on ground, cov. with hay	February 27-May 18	...	4	13	127
II. MECHANICAL INJURY						
4*	Bark gashed; in 4 degrees of sun and shade (NB)	May 21-November 17	8	0	21	469
5*	Bark gashed; in 4 degrees of sun and shade (NB)	May 21-November 17	14	0	18	378
6*	Bark pounded; in 4 degrees of sun and shade (NB)	May 21-November 17	0	0	22	568
7*	Bark pounded; in 4 degrees of sun and shade (NB)	May 21-November 17	20	0	19	367
8*	2 pounded logs and 2 gashed logs hung in tree (NB)	May 21-November 17	0	0	19	612
9*	2 pounded logs and 2 gashed logs; deep shade (NB)	May 21-November 17	100	...	24	0
10*	2 pounded logs and 2 gashed logs; part shade (NB)	May 21-November 17	0	0	21	817
11*	2 pounded logs and 2 gashed logs; in full sun (NB)	May 21-November 17	16	0	17	353
12	Gashed log, on ground, in part shade (NB)	June 10-July 14	31	100	10	6
13	Same as 12, but BI	June 10-July 14	...	17	10	6
14	Pounded log on ground, in part shade (NB)	June 10-July 14	72	0	9	2
15	Same as 14, but BI	June 10-July 14	...	33	10	9
16	Gashed; on ground †, in sun, hay cov., watered † (BI)	June 25-July 23	...	9	52	623
17	Gashed; on ground †, deep shade, hay, watered † (BI)	June 25-July 29	...	62	54	360
18	Gashed; on rack in sun, stacked (BI)	June 25-July 24	...	31	47	532
19	Gashed; on rack in deep shade, stacked (BI)	June 25-July 23	...	40	49	622
20	Gashed; stood on end, pyramid-form; part shade (BI)	June 25-July 23	...	15	21	232
21	Pounded, † covered with wet † hay, deep shade (BI)	May 25-November 16	...	85	6	59
22	Gashed † covered with wet † hay, deep shade (BI)	May 25-November 16	...	78	6	31

23	Gashed, on rack in sun, single (BI).	May 25–November 16	...	60	6	26
24	Pounded, on rack in sun, single (BI)	May 25–November 16	...	98	5	44
III. HOT WATER						
25	Immersed in water at 127° F. 15 min. (BI)	June 25–June 29	...	0	4	211
26	Immersed in water at 137° F. 1 hour. (BI)	June 26–June 29	...	100	4	306
IV. FLAME						
27	Flamed w. blowtorch weed killer until slightly charred (less than 5 min.) (BI)	June 26–July 2	...	100	4	235
V. SUN EXPOSURE						
28	Logs in full sunlight, not rolled (BI)	June 22–July 17	...	38	52	61
29	Logs in full sunlight, rolled every 4th day (BI)	June 22–August 3	...	100	11	4
VI. LIVE STEAM						
30	BI stovewood, 1/4 cord piled, cov. w. canvas Steam piped into center of pile, 1/2 hour.	summer	...	100	All parts sampled	Numerous
31	BI 4 1/2 foot logs, 1/8 cord, cov. w. canvas. Steam piped into center of pile, 1/2 hour.	fall	...	97	49	686
VII. FUMIGATION						
32	<i>Chlorofictin</i> . 37 3-foot logs, BI in all stages 1 pound per 1000 cu. ft. poured on cloth in center of pile. cov. w. canvas for 8 days.	August 12–August 20	...	0	Random samples	Numerous
33	<i>Calcium cyanide</i> . 35 8-foot logs; BI, all stages 3 pounds per 1000 cu. ft. sprinkled among logs cov. with canvas for 8 days.	August 14–August 20	...	0	Random samples	Numerous
34	<i>Paradichlorobenzene</i> . 1/4 cord stovewood. BI, overwintering larvae. Crystals at rate of 5 pounds per cord sprinkled among logs. Pile cov. with hay all winter.	November 12–June 16	...	0	5	198

*See explanation preceding table.

†The logs in item 16 and 17 were stacked; those in items 21 and 22 were arranged singly on the ground.

"Wet hay" was wet, molded and beginning to decay when placed over the logs; "watered" hay was freshly cured hay which was sprinkled thoroughly with water immediately after the logs were covered.

In items 4 and 6 the ends of the logs were paraffined to retard drying. In items 5 and 7, the ends were not paraffined. In items 8 through 11, each group of 2 logs included one paraffined and 1 unparaffined log.

Results: Summary of experiments other than spraying. Refer to table 5.

I. Covering of uninfested wood with hay prevented infestation by bark beetles, but did not result consistently in appreciable mortality in infested wood.

II. Injury to the bark caused by scoring or pounding did not affect the logs in such a way as to render them unsuitable for either entry or breeding when conditions were otherwise suitable and when the injury was made during the summer or shortly before the beetle flight season. However, in situations already unfavorable for the beetles, such as storage on a rack in full sunshine, or coverage with wet hay, bark injury may render such conditions even more unfavorable by causing the bark to dry out more quickly in the former location or by facilitating mold and decay in the latter situation if the wood is in deep shade or in a moist location. Reference has already been made to the possibility of combining spray treatments with mechanical injury. The results of injuries made during the winter have not been checked, but evidence from trees attacked by woodpeckers indicates that this type of injury made during the winter season does not always result in a heavy mortality of the larvae which remain.

III. Beetles in all stages were killed by immersing the wood for an hour in water at an initial temperature of 137 degrees F. The minimum effective time and temperature limits have not been determined, but are probably less than those given.

IV. Scorching the bark with a blowtorch of the weed killer type resulted in complete mortality. The temperatures reached, or necessary to be reached, between the bark and the wood, were not determined.

V. The simple expedient of turning over a log exposed to the sun every few days during the summer, giving it about a quarter turn each time, resulted in complete mortality, whereas in logs which were not turned the larvae on the under sides survived.

VI. With live steam piped from a boiler into a pile of stovewood covered with canvas, a virtually complete mortality was obtained. In one experiment, 97 per cent mortality, by count, was achieved with steam piped intermittently and not at the same pressure, for half an hour. In the other test, the steam was piped continuously at even pressure for half an hour, with complete mortality resulting in all the samples examined.

VII. Fumigation with the materials tested under field conditions (chloropicrin, Cyanogas and paradichlorobenzene) did not result in

measurable mortality. Franzen has reported similar results from HCN fumigation and also from carbon bisulfide.

III. DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

The results of the experiments discussed in this bulletin lead to the conclusion that although there has been found no completely satisfactory alternative for the removal and burning of dead and dying elm wood to prevent the breeding of elm bark beetles carrying the Dutch elm disease pathogen, there are several simple methods of caring for elm wood which may frequently be the only methods that can be used at a given time and place, and which can be expected at least to reduce, if not to eliminate, the dangers of attack and emergence of bark beetles. Our specific conclusions are implied in the following suggestions and comments.

Leave *uninfested* cut wood or broken limbs on the ground in continuous dense shade, hidden in heavy ground-cover, to minimize the danger of attack by *Scolytus multistriatus*. Wood left in only partial shade, such as a broken branch partly shaded by foliage, or a log in a clearing, is likely to attract beetles which can establish successful colonies.

Leave *infested* wood in the sun, with the pieces separated and not touching the ground, on a dry site not overgrown with grass, weeds or brush. Wood can be successfully exposed in this way in the hot periods of summer. If the wood is turned over from time to time so that it receives hot sun exposure on all sides, emergence is often entirely prevented.

In the winter, well exposed wood is especially subject to attack by woodpeckers, which may destroy all or most of the larvae in a given location. On the other hand, moderate woodpecker activity does not always destroy all the larvae, and where the bark is not too severely damaged, emergence can occur.

Regardless of the method of exposure or storage of elm wood, it should never be left in, under, or near valuable elm trees, since the beetles tend to feed near their place of origin, and to a lesser extent, near their place of entrance. (Collins, D. L., 1939; Franzen, 1939; Wolfenbarger and Buchanan, 1939; Wallace, 1940; Collins, D. L. and associates 1940; Wolfenbarger and Jones, 1943).

Uninfested wood in any situation, if covered with a good layer of hay (about four inches thick in our tests) with no surfaces exposed or protruding, can be expected to remain uninfested. Covering with such a layer of hay does not prevent emergence from wood that is already infested.

Logs that have been scored, pounded, or bruised, readily become infested, and under suitable breeding conditions can produce large

numbers of beetles in spite of the mechanical injuries to the bark and wood. However, such treatment should be more effective when executed under adverse beetle breeding conditions. Oil treatments of such wood should be more effective than oil treatments of sound wood.

Treatment of wood with fire, steam, or hot water may sometimes be feasible, and, if properly done, can be expected to result in very high to complete mortality of the beetles present. In the fire treatment, an extremely high temperature, such as that produced by the flame from a blowtorch, must be used. The steaming method would seem to be more adaptable to compact piles of stovewood which can be covered by a tarpaulin, whereas the blowtorch could be applied more easily to a single log. The hot water method would involve individual dipping of logs, unless large quantities of small logs could be dumped into tanks of hot water. The possibilities in these heat treatments have not been adequately explored.

Wood which is covered by a spray consisting of a light petroleum oil base, with the addition of creosote and a fumigant such as paradichlorobenzene or orthodichlorobenzene (that is, formulae LT-29, LT-30, LT-34) may be protected from beetle attack provided the treatment is made under the proper conditions. For repellency, complete coverage of all parts of each piece of wood in a pile appears to be unnecessary, so that entire small piles of wood can sometimes be successfully treated. But to kill larvae in infested wood, complete coverage of all parts of each piece of wood is essential, the spray must be applied during a period of high temperature in the summer, and the wood must be left in the sun. When the beetles are in the prepupal or pupal stages, the results are likely to be erratic. It is probable that a simpler formula, such as LT-1 (creosote in kerosene) is just as effective a repellent as the mixtures containing a fumigant. It is also possible that one of the simpler formulae, such as sulfate wood turpentine, may produce a satisfactory mortality in infested logs.

The results of tests with chemicals on logs with thick bark are not encouraging. The bark on most of the material treated in the majority of the tests reported here was only $\frac{1}{8}$ to $\frac{1}{4}$ inch thick from wood to outer bark. From the observations on the material in this range, it was indicated that chemical control on thick-barked infested material would be doubtful.

It is the spring-emerging beetles, that is, those which are in the larval stage in logs during the winter, that are the most important as carriers of the Dutch elm disease pathogen to healthy trees. The fact that infested wood in the field cannot be treated successfully in the winter by the chemicals tested is therefore a serious objection to this method of treatment. Winter is usually the most convenient time for organized control work since labor, in normal times, is more generally available

at that time and extreme haste in disposing of material is not necessary. Chemical treatment of infested wood with any assurance of success in destroying the overwintering brood would have to be made during the late summer or early fall. It is the authors' opinion, therefore, that in community control work, chemical log treatments have only a small place in the Dutch elm disease control program, unless DDT sprays should prove exceptionally successful and economical. The individual owner would more often be in a position to use chemical methods of treatment, especially where the desirability of reserving wood for fuel was the deciding factor.

In view of the limited period during which chemical treatment can be successful, it is concluded that natural and mechanical means of inhibiting beetle entrance and reducing beetle emergence, coupled with removal and burning wherever possible, are the best practical measures of disposing of any elm wood that is considered a hazard in the Dutch elm disease control program.

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